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GUIDANCE RELATED TO THE EFFICACY OF MEASURES USED TO MITIGATE POTENTIAL IMPACTS OF SEISMIC SOUND ON MARINE MAMMALS

Figure 1: Map of Canada.

Context :

During marine seismic survey operations, companies are required to use a basic set of measures to minimize the acoustic disturbance to marine mammals, as outlined in the Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment. These mitigation measures can be grouped into three categories: planning measures, operational measures and additional measures as required by site-specific environmental assessments.

Recently, questions have arisen regarding the level of effectiveness of the mitigative measures set out in the Statement under the various environmental conditions in which seismic surveys are conducted in non-ice covered marine waters in Canada. As such, the Oceans, Habitat and Species at Risk (OHSAR) Sector of the DFO sought guidance from Science Sector on the conditions and extent to which the effectiveness of the operational mitigative measures set out in the SOCP might vary with environmental conditions, and if so, the nature of the variation. Fisheries and Oceans Canada hosted a National Science Advisory Process meeting on May 12 – 13, 2009 to provide advice on the effectiveness of mitigations.

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Canada

SUMMARY

- A review was conducted looking at the conditions and extent to which the effectiveness of the operational mitigations set out in the Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment might vary with environmental conditions.
- A number of specific factors were considered:
    - Establishment of a Safety Zone
    - Factors Influencing the Ability of Marine Mammal Observers (MMO) to Detect Marine Mammals
    - Factors Influencing the Effectiveness of Passive Acoustic Monitoring (PAM) in Detecting Vocalizing Marine Mammals During Standard Operating Conditions of a Seismic Survey
    - Factors Affecting the Effectiveness of Ramp Up
    - Planning and Design; Objectives and Outcomes
- Suggested areas for further research were also identified:
    - Active acoustics
    - Building a larger signals library for PAM
    - Autonomous PAM on underwater gliders
    - Technology and tools to implement and support the use of standardized reporting, data collection and data management for MMOs and modeling.
    - More environmentally benign alternatives to air guns.
    - Additional research on the behaviour of marine mammals after ramp-up or shutdown is needed in order to verify that these measures effectively work (i.e., that mammals leave an area).

INTRODUCTION

The Canadian Science Advisory Secretariat hosted a meeting on May 12-13, 2009 to examine the effectiveness of measures used to mitigate the effects of seismic sound on marine mammals. The meeting was attended by 43 participants including federal and provincial government experts as well as experts from academia, environmental non-government organizations, industry and the three Regulatory Boards (i.e., the National Energy Board, the Canada-Nova Scotia Offshore Petroleum Board and the Canada-Newfoundland and Labrador Offshore Petroleum Board).

Seismic exploration is undertaken in an international context. Many other countries have adopted similar mitigation approaches to those used in Canada. In addition, other countries have begun to develop regulations and guidelines in order to develop standard national approaches to mitigate the effects of seismic sound on marine mammals. In Canada, the Departments of Fisheries and Oceans (DFO), Natural Resources Canada and Indian and Northern Affairs, in collaboration with provincial governments, have compiled a set of mitigation measures into the *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment* (SOCP) (DFO, 2008). The SOCP sets out minimum standards which apply in Canada's non-ice covered marine waters to all seismic activities that use air source arrays.

Recently, questions have arisen regarding the level of effectiveness of the mitigative measures set out in the *Statement* under the various environmental conditions in which seismic surveys are conducted in non-ice covered marine waters in Canada. As such, the Oceans, Habitat and

Species at Risk (OHSAR) Sector of the DFO sought guidance from Science Sector on the conditions and extent to which the effectiveness of the operational mitigative measures set out in the SOCP might vary with environmental conditions, and if so, the nature of the variation.

The SOCP sets out minimum national standards for mitigation of impacts of seismic sound on marine organisms. The Statement of Practice is flexible, to allow regulatory bodies (federal and joint federal-provincial) to adapt the regulatory requirements for any specific application to the specific circumstances of the proposal. The regulators are explicitly encouraged to set case specific requirements above the minimum standards in the Statement of Practice, whenever warranted by the specific cases.

This flexibility of practice is necessary to allow regulators to deal with the diverse ecological conditions around Canada's oceans, and the variety of industrial applications of seismic sound. However, the flexibility of application also means there may be a risk that specific suites of regulatory requirements may not deliver the desired conservation outcomes. Failure to achieve desired outcomes could occur if the requirements for conservation in particular cases are not adequately assessed, if the mitigation measures are not matched well to the conservations needs, or if sufficient precaution is not applied in the face of high scientific uncertainty and risk of serious harm to components of the marine ecosystems.

This advisory is intended to provide scientific guidance on how managers and regulators should exercise the flexibility designed into the Canadian Statement of Practice. In particular the guidance clarifies the factors which affect (negatively or positively) the effectiveness of alternative measures to protect marine mammals from harm by seismic sounds, and where appropriate things that can be done to reduce the impact of the factor(s) on the mitigation measures. The guidance is not tied to delivery of particular outcomes, because it became clear during the meeting that not all of the desired conservation outcomes of management have been specified yet, and even those that have been specified may be revised in future, as more knowledge is acquired about marine ecosystems, marine organisms, and effects of seismic sound. Similarly, the guidance is not tied to achieving any specified level of risk aversion, as risk management is the responsibility of the regulatory authorities.

Rather the guidance is intended to both aid managers in delivering desired outcomes, when they have been specified for a particular application, and to inform dialogue, when environmental assessment and/or consultation is being pursued in part to obtain (directly or indirectly) societal consensus on desired outcomes and risk tolerances. Even if governance processes add to or alter the desired outcomes in future, the guidance on application of the various mitigation measures should remain valid. However, because both knowledge and practical experience are increasing with research, monitoring, and assessment of impacts, it would be appropriate to revisit this guidance periodically, and update it as appropriate to accommodate the new knowledge. Similarly, outcomes and minimum standards for managers to apply should be revisited periodically, to ensure "best practices" are indeed the best ones, given the full body of scientific and technical information available.

ANALYSIS

Establishment of a Safety Zone

The Statement of Canadian Practice defines the safety zone as "a circle with a radius of at least 500 metres as measured from the centre of the air source array(s)". However, the SOCP does not provide the specific objective of establishing the safety zone or the rationale for using 500 m as a minimum safety zone radius.

The recommended 500 m safety zone is not directly related to thresholds for hearing impairment, injury, or significant behavioural responses in marine mammals. The actual radius where any given effect would occur will vary widely depending on characteristics of the airgun array and local sound propagation conditions. Therefore, sound propagation models should be used to establish seismic signal propagation characteristics and subsequently the safety zone for marine mammals during the planning stage of a seismic survey where applicable.

When modelling is applicable, both the magnitude and frequency characteristics of the seismic source output should be modelled at relevant points in space and time in order to minimize the seismic source output but at the same time achieve the objective of the survey.

Sufficient background information should be available to support effective modelling and include:

Geophysical and oceanographic data;
Distribution of noise source and biological receivers in space and time; and,
The range of variation in this information.

Modelling will be significantly less effective where source-specific, operations area-specific or species-specific data are not available to parameterize the model.

The choice of the propagation model should be applicable to the intended operating environment and frequency range of the seismic source output.

Cumulative Sound Exposure Level (CSEL) is a more biologically relevant metric than just root mean square (rms) alone for sound modelling and describing model output. Models used to establish seismic signal propagation should be capable of producing at least both CSEL and rms metrics. Depending on the objectives of pre-survey modelling, other output metrics should also be considered (i.e. sound exposure level [SEL], peak sound pressure level and M-weighting).

A desirable approach should include exposure criteria which employ receiver hearing weighting (e.g. M-weighting) for sensitive or important marine species – factor in the identities and hearing capabilities of key receivers in the modelling exercise.

If modelling impacts, then to the fullest extent possible, use information on the species and conditions that are present in the area. When information specific to the particular application is not available, many experts consider Southall *et al* (2007) a good starting point.
While not all sound propagation modelling outputs will require field verification, there are circumstances that will necessitate the validation of pre-survey modelling results. These factors include:

i. SARA-listed species (i.e. sound receptors) present in the area expected to be ensonified;
ii. Seismic operations expected to occur in shallow waters (i.e.<200 m);
iii. No previous field verification of the model or context;
iv. Seismic operations expected to occur in non-uniform areas with respect to geophysical and/or seasonal characteristics; and,
v. Multiple operations might necessitate studies of long-range propagation.

Further Considerations

At present, field verification methods are not standardized and are often inconsistent. Standardization of these methods is recommended.

Although seismic airgun arrays are known to have high frequency components, most of the current seismic source models demonstrate their best predictive scope in the lower end of the acoustic frequency range (i.e. ≤ 200 Hz). Further work should be invested in high frequency source modelling to better match model operational range to the broadband output of seismic arrays and the hearing ranges of species of interest. *Note: Impacts of concern are not restricted to the frequency range where current models work well; this is a limitation of current modelling at this point.*

Propagation models could be improved by using ancillary data collected during a seismic survey. For example, ocean bottom seismic (OBS) receiver data might provide useful field data on sound speed or seismic signal strength for verification of acoustic propagation models. Towed seismic streamer data, or other near real-time, site specific measures (e.g. XBT or CTD casts) might provide useful real-time information about the acoustic properties of the water column for model verification. The usefulness of such data would have to be investigated on a case-by-case basis.

Modelling so far has focused largely on hearing impacts. As knowledge accumulates, modelling should take other information into account (i.e. non-auditory or behavioural impacts; improved understanding of auditory ranges of receiver species).

Factors Influencing the Ability of Marine Mammal Observers (MMO) to Detect Marine Mammals

The goal of a seismic survey that utilizes Marine Mammal Observers as part of the program is to maximize the ability of the MMOs to:

i. Detect marine mammals within or about the safety zone; and,
ii. Guide the implementation of appropriate mitigation measures.

Attaining this goal will depend upon the training and experience of the MMOs as well as the equipment and protocols established for a specific survey.

The Statement of Canadian Practice indicates that a "qualified Marine Mammal Observer" must observe the safety zone. However, the SOCP does not define "qualified". Therefore, the following recommendations are offered:

i. MMO training and qualification should be standardized.
ii. Specific seismic survey planning should consider:

- A minimum number of qualified MMOs (appropriate to specific characteristics of the area/project).
- For seismic surveys in areas where marine mammals could occur, priority should be given to MMOs (over, for example, researchers).
- Maximizing the number of MMOs on watch simultaneously, subject to operational logistics.
- Possible benefits of placing MMOs on a support vessel in addition to the source vessel.
- Setting a maximum shift length and total duty time per day (shorter, more frequent watch shifts are better than long ones).
- Specifying that when MMOs are on duty, they should not be responsible for anything else.

Environmental factors that reduce the ability of an MMO to observe marine mammals are: darkness/low light; sea-state/swell; glare; and, precipitation/fog (Harwood and Joynt 2009; Moulton *et al.* 2009). Water turbidity has also been identified by Moulton *et al.* (2009) as a factor that can reduce MMO efficacy but within the Canadian context, this factor is limited to the Mackenzie River estuary.

While acknowledging that the operation of seismic vessels in poor weather is strictly governed by federal regulations, nevertheless, Marine Mammal Observers must have adequate training and experience to determine the environmental conditions in which they can perform their duties properly and under what conditions to cease observations and/or call for a shutdown as they deem appropriate. Specifically, it is recommended that:

- The MMO has the right and responsibility to identify conditions under which they cannot do their job effectively;
- The operational procedures of the survey incorporate provisions addressing what would happen under those situations; and,
- Shift duration for MMOs should be based on a number of factors including weather, visibility, number of whales, etc.

The observation post of an MMO onboard a vessel and the optical equipment used to search for marine mammals has a direct bearing on the effectiveness of the observer. Thus it is recommended that:

- The highest safe lookout with no obstruction to 360° visibility be made available for the MMOs; and,
- High quality optical equipment is used.

It is also recommended that MMO data recording and reporting be standardized and that the MMO data sets from individual seismic surveys be archived in a central location that is easily accessible by interested parties.

Factors Influencing the Effectiveness of Passive Acoustic Monitoring (PAM) in Detecting Vocalizing Marine Mammals During Standard Operating Conditions of a Seismic Survey.

Passive Acoustic Monitoring (PAM) is employed as a complement to visual observations when the latter monitoring technique is compromised by poor visibility or when marine mammals are below the surface or beyond visual range. The effectiveness of PAM can be reduced by the following factors: ability to detect target animals, localization of signal, signal classification, and operational characteristics.

Factors Affecting Detection

Biological

Silent animals cannot be detected and weak vocalization signals have a low probability of being detected. Where a number of marine mammal species are present in the survey area and are vocalizing, the sounds being emitted will have a range of frequencies (both low and high frequencies) and amplitudes. The effectiveness of a PAM array is directly related to its ability to receive a broad range of frequencies and characteristics of marine mammal vocalizations.

Ship Noise

Ship noise increases background noise making the detection of marine mammal vocalizations difficult – the interference being more pronounced at lower-frequency ship noise than higher-frequencies.

Airgun Array Noise

The effectiveness of PAM is likely to decrease during the operation of a seismic airgun array. The decline in effectiveness, which may be significant, will depend on operational procedures such as using a fixed PAM array versus one that is towed and, the position of the PAM array with respect to the airgun array when both are being towed.

Environmental Noise

Ambient noise (e.g. ice, wind, rain, and biological noise), while being a factor that can contribute to reducing the effectiveness of PAM, is more of an issue for fixed PAM.

Factors Affecting Localization

It is quite difficult, if not impossible, to determine the location or distance of a marine mammal in relation to the safety zone when using the standard approach of towing a single hydrophone array from the seismic source vessel. When a single hydrophone array is used, localization is only possible if the vessel changes course while a series of repeated vocalizations are detected, in which case triangulation can be performed. However, during seismic surveys it is undesirable for the seismic source vessel to change course off the planned survey lines, as seismic data will be compromised.

Factors Affecting Species Classification

Currently, unidentified detections of marine mammal vocalizations require additional mitigation measures (see section 12 of the SOCP). Furthermore in Canada, under SARA there is a requirement to identify listed species; this requires species classification. Challenges exist in getting reliable and timely classifications – including the following: a) unknown vocalization characteristics; b) classification algorithms; c) unidentified sounds and non-signature sounds.

Factors such as the frequency and duration of calls; number of animals calling; and, diversity of species that may be present in a seismic survey area can influence the ability of PAM to differentiate and classify vocalizations. During the operation of a PAM system,

streams of sound may be received for which the technology does not have good, reliable automated ways to classify. Also, some sounds (e.g. clicks) can be issued by many different species including some that are not marine mammals.

Operational Characteristics

There is no existing set of standard operational procedures or guidelines to manage the operations of PAM. As well, there is a need for skilled and trained staff and the program with which to train them.

Recommendations for the Use of PAM

It is suggested that:

A PAM array should possess the capability of detecting a wide range of frequency and characteristics of marine mammal vocalizations.

To reduce the influence of anthropogenic noise (i.e. ship and airgun noise) on a PAM system, tow the PAM array from a guard vessel at long distance away from the seismic source vessel; use directional receivers and signal processing; use surface-linked fixed or drifting receivers at distances away from the seismic sound source.

Localization of vocalizations in relation to the safety zone could be improved by towing two hydrophone arrays from the seismic vessel.

Standard procedures and guidelines are required which include definitions of roles and responsibilities.

Training / skilled staff - The experience level of the operators is crucial. There is currently a very limited pool of experienced people, especially locally. Capacity could be increased by training, and by standardization of equipment, set-ups and user interfaces (especially for mobile PAM deployment; for fixed PAM, the data can be send to a centre of expertise).

Factors Affecting the Effectiveness of Ramp Up

The goal of the ramp-up or soft start is to allow marine mammals that are close to the airgun array to move away before they are exposed to the full output of the airgun array. The assumed objective of this mitigation measure is to reduce any potential for hearing damage.

The use of ramp-up is based on logic and supported by observations but its effectiveness as a mitigation has yet to be confirmed empirically. In addition, there are circumstances where marine mammals may not avoid sound sources. The motivation of animals to leave an area is known to vary on a number of factors.

There is some debate over which is the more effective ramp-up process: a 20 minute duration ramp-up or the rate of increase of the number of air guns in the array up to operational strength. With a ramp-up mitigation based on a duration of at least 20 minutes, the mitigation can be tailored to a specific project based on the species known to be in the area (e.g. longer duration when deep-diving species are know to occur) and on the likelihood of detecting marine mammals based on environmental conditions (i.e. when the safety zone cannot be visually monitored effectively).

Recommendations

1) To the extent practical in the planning stages of a seismic survey, establish pre-determined, project-specific incremental increase of sound source level.
2) Establish whether the safety zone during ramp-up must be the same size as that during operations. If the safety zone is >500 m, the pre-ramp-up watch exclusion zone must be a minimum of 500 m, but does not have to be of the same size as the full airgun array volume safety zone.
3) Conduct a detailed investigation of how duration and position of pre-ramp-up watch should be linked to ramp-up and the speed of the vessel as well as water depth (deeper diving and/or longer diving species).
4) Periodic efforts are needed to consolidate MMO data. These data should be reviewed and used to update/change operational guidelines and standards in conjunction with regulatory framework reviews.

Further Considerations

- Under section 7 a (i) of the SOCP, delay of ramp-up is required if cetaceans or sea turtles are observed within the safety zone. Pinnipeds should also be included.
- Ramp-up not required if airgun array is not active for more than 30 minutes.
- Ramp-up not required when seismic surveys, using a single airgun source, resumes after a shut-down period.
- A research program to systematically assess the overall effectiveness of ramp-up.

Planning and Design; Objectives and Outcomes

While these two topics are clearly outside the terms of reference of this review – that is, the consideration of those operational mitigation measures set out in the Statement of Canadian Practice – the workshop participants felt that observations made on planning and design and, objectives and outcomes would compliment the operational recommendations and therefore should be included in the advisory.

The most effective mitigation is proper planning well in advance of seismic surveys. Good planning should avoid or reduce impacts on life functions of marine mammals. With incomplete knowledge of where these functions occur, this objective is often achieved by avoiding concentrations of marine mammals, spatially and temporally. Planning for this avoidance requires primarily good baseline surveys of marine mammal distribution and overall biological information. Habitat modeling can also be instrumental in focusing survey efforts on most important areas. Good communication between all stakeholders and access to knowledge as soon as possible is critical.

The cumulative effect of multiple noise sources should be assessed when considering cumulative impacts. Additionally, other threats to marine life and their possible interactions (synergistic, additive, antagonistic) should be taken into account when planning mitigation measures. If marine mammals are facing added stressors such as chemical pollution, by-catch, climate change, or food scarcity, more stringent mitigation measures may need to be incorporated or seismic surveys may be inappropriate for that area. Over the longer term, models and research for rigorous cumulative impact analyses should be developed.

Four factors can influence the effectiveness of planning and design. These factors are:

1. Seasonal, geographic, timing;
2. Airgun array size, configuration, line design, direction;
3. Actions to avoid significant negative population effects; and
4. Studies on effects on marine mammals (including cumulative effects).

Seasonal, geographic, and timing factors

At the planning and design stage, it is important to have as much information and data as possible on the background conditions of the survey area (e.g., biological information, seasonal information, geographic information, environmental trends, biotic or abiotic changes to the environment etc.). It is also important to involve stakeholders early in the process both to seek their advice/knowledge and to inform them about the planned activities.

Airgun array size, configuration, line design, direction

Optimize source levels to balance the geophysical and environmental objectives with operational objectives (e.g. for scientific studies, minimize energy levels and number of track lines, optimize airgun configuration)". Also, investigate alternatives to air guns in the planning phase.

Actions to avoid significant negative population effects

The following six actions that can be taken during the planning stage to avoid significant negative population effects:

1. Population consequences of acoustic disturbance (PCAD) is a useful logical framework (or structure) to consider impacts;
    - data is needed to inform the framework (model) parameters
    - PCAD could provide information for environmental assessment
2. application of precaution;
3. Environmental Assessments / monitoring plan / mitigation;
4. Lack of consolidated suite of outcomes required under Canadian legislation, especially associated with defining and measuring 'significant negative population effects';
5. Standardize methodology for data collection and reporting requirements; and,
6. Investment is required for adequate planning and research.

In the years since 1996/7, when CSAS was formally established, considerable advice on "how to" has been generated. As such, a compilation of previous advice and desired outcomes related to offshore seismic surveys would be useful. This could be accomplished by the following actions:

1. Examine the Acts and regulations for which DFO is responsible for enforcing, and for which actions Science advice is needed, as well as the new major international agreements. For each one, extract the provisions that directly require science advice to implement and/or specify the nature of the outcome that must ensue from DFO management / policy interventions. These can then be sorted into coherent sets based on a question such as, "What level of protection is DFO required to give marine mammals relative to seismic sound?"

2. Examine all the past CSAS Science Advisory Reports (SAR) that are collectively referred to as "guidance documents" – that is, how to do a particular task that DFO is required to do. There are a number of "guidance documents" related to Oceans management (e.g. EBSA and EBSS criteria) and SARA. Tabulate the guidance and what application the guidance addresses, and which SAR it appears in.

A cross-walk of 1 and 2 will help in priority setting by clarifying what major things DFO Science is supposed to provide advice on, but for which there is no guidance on how to develop the advice in a consistent manner. The cross-walk will also help in individual CSAS meetings by giving quick access to topics for which advice is already available, and where to find it. It is rapidly becoming impractical to relay on corporate memory of meeting participants to be sure that well-invented wheels get used, rather than re-invented.

Studies on effects on marine mammals (including cumulative effects)

Key factors in planning such studies are:

- A clear statement of the research questions which are defined in the context of a particular seismic survey; and.
- Proper study design including high statistical power.

Few tools are available to assess cumulative effects and these types of assessments can be hampered by:

- Drifting environmental baseline;
- Difficulty in extrapolating individual effects to population level; and,
- Interaction of unknown stressors.

Objectives and Outcomes

Standards, models, methods and guidelines are not ends in-and-of themselves, rather they are framing tools used to achieve objectives and desired outcomes, which will necessarily require adaptation to advances in technology and understanding of environmental conditions.

Practices advanced by these regulations [read: standards, models, methods, guidelines, codes-of-practice and regulations] need to be framed by, and tailored to the objectives of SARA, fisheries recovery priorities and the long term sustainability of Canadian environment, food and cultural legacies.

Any activity subject to these regulations [read: standards, models, methods, guidelines, codes-of-practice and regulations] should invite input from impacted stakeholders to craft practices consistent with local, regional and national priorities.

Objectives and desired outcomes have been developed over time and exist in several documents both nationally and internationally (e.g., SARA, Fisheries Act, Oceans Action Plan). Thus, it was recommended that DFO review all relevant documents to compile a list of these identified desired outcomes. This compilation could be made available to management and others to enhance knowledge and understanding of goals and outcomes with respect to marine mammals. The compilation should be accompanied by an acknowledgement that while mitigation measures must contribute to the achievement of desired outcomes, they must also be operationally feasible and practical.

CONCLUSIONS AND ADVICE

The Research and Development (R&D) recommendations listed below are not aimed at any particular government agency, regulatory body or offshore oil and gas company. Rather, they are presented in the hope that a collegial effort can be mounted in the future that will advance our collective knowledge regarding the mitigation of the impacts of seismic sound on marine mammals. The recommendations are listed below in no particular order of priority or importance:

- Active acoustics
- Building a larger signals library for PAM
- Autonomous PAM on underwater gliders
- Technology and tools to implement and support the use of standardized reporting, data collection and data management for MMOs and modeling.
- More environmentally benign alternatives to air guns.
- Additional research on the behaviour of marine mammals after ramp-up or shutdown is needed in order to verify that these measures effectively work (i.e., that mammals leave an area).

SOURCES OF INFORMATION

DFO 2008. Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment. Available: http://www.neb.gc.ca/clf-nsi/rthnb/nrthffshr/pblctnrprt/gdlnthrzt-eng.html

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